Proposal for MRes CMEE Dissertation Project

PokMan HO (CID: 01786076)

Department of Life Sciences, Faculty of Natural Sciences,

Imperial College London

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Primary supervisor:

Dr. James Rosindell

Department of Life Sciences (Silwood Park), Faculty of Natural Sciences, Imperial College London

email: j.rosindell@imperial.ac.uk

Secondary supervisor:

Dr. Samraat Pawar

Department of Life Sciences (Silwood Park), Faculty of Natural Sciences, Imperial College London

email: s.pawar@imperial.ac.uk

1 Keywords

ODE model, ecological photovoltaics, electricity, carbon sequestration, co-existence, nutrient cycling

2 Introduction

Two main substrates were able to print cyanobacteria for electricity: *Synechocystis sp.* on carbon nanotube-coated paper (Sawa et al. 2017) and *Anabaena sp.*on mushrooms (Joshi, Cook, and Mannoor 2018). Both successfully generate small photocurrents (micro-ampere on paper (Sawa et al. 2017) and nano-ampere on mushrooms (Joshi, Cook, and Mannoor 2018) respectively). Under the urge of clean energy due to climate change (Schuur et al. 2015), our civilization needs electricity as well as carbon sequestration services simultaneously and quickly. We can augment photosynthesis by inserting carbon nanotubes inside phytocells (Giraldo et al. 2014), or incorporate biodiversity. Primitive extremophile *Chroococcidiopsis thermalis* were found extremely tough (Baqué et al. 2013) and able to utilize extra far red spectrum as photosynthetic light source (Nürnberg et al. 2018). If this lineage is able to provide photocurrent, it would be a step towards the solar-powered civilization.

With ecology in mind, this project aims at finding the theoretical recipe to make a multi-spectra bio-solar panel with carbon sequestration ability. The research questions are:

- When would the coexistence system be stabilized?
- How do *Anabaena sp.*, *Chroococcidiopsis thermalis* and the bio-substrate interact?
- What is the expected performance on electricity generation and carbon sequestration based on this ecosystem?

3 Proposed methods

A set of ordinary differential equations (ODEs) would be implemented as a Lotka-Volterra model (LVM). The cyanobacteria-mushroom system (Joshi, Cook, and Mannoor 2018) would be the stem of this model. Nutrients were assumed to be unlimited because wastewater was potentially an all-rounded fertilizer for cyanobacteria (Markou, Vandamme, and Muylaert 2014) The main equations included would be:

$$
\begin{array}{r|ll}
\textit{Anabaena sp.} & dA/dt & = [r_A A] - [k_{A1} A] - [k_{A2} AC] - [K_M] \\
\textit{Chroococcidiopsis thermalis} & dC/dt & = [r_C C] - [k_{C1} C] - [k_{C2} AC] - [K_M] \\
\textit{mushroom} & dM/dt & = [r_M M] - [k_M M]
\end{array}
$$

Left hand side half equations were instantaneous growth rates of representative populations. The first and second terms of the right hand side half equations were natural growth and death rates. For cyanobacteria species, another two terms were added, symbolizing growth hinder by competition and population loss upon mushroom death. Assuming same growth conditions between *Anabaena sp.* and *Chroococcidiopsis thermalis*, the competition for space would be the only battle ground. By modelling how this system react to isolation cycles would provide insight on future engineering design of the true panel.

Natural growth and death rates for all three bio-players could be extracted in literature. Assuming both

cyanobacteria lineages only compete by growth, competition coefficient can be estimated by their difference in light harvesting ability. This ratio would be a fraction further modified by their growth rate: $k_{A2} = \frac{J_{Ct}}{J_{As} + J_{Ct}} \cdot r_A$ & $k_{C2} = \frac{J_{At}}{J_{As} + J_{Ct}} \cdot r_C$, which energy harvested by *Anabaena sp.* per cell per unit time was J_{As} and that by *Chroococcidiopsis thermalis* was J_{Ct}.
Competition coefficients k_{A2} & k_{C2} of one species was depending on how better the other one did from its (i.e. the fraction). This term was also positively depending on its natural growth rate. Logically the higher its growth rate, the bigger hinder effect it would be.
By assuming *Anabaena sp.* layer printed on mushroom was a single cell layer on published article (Joshi, Cook, and Mannoor 2018), ratio between given light energy and photocurrent per photocell of *Anabaena sp.* could be calculated because of known cell size. Photocurrent strength per cell could also be calculated for given solar wavelength. By linking photocurrent size with population, expected electricity output per time step could be obtained. On the other hand, carbon sequestration ability could also be estimated through biomass growth (Markou, Vandamme, and Muylaert 2014).

4 Anticipated outputs and outcomes

From the simulation, there would be a graph of population sizes for all ecological parties upon solving the equations. Hence time of achieving population dynamic equilibria and expected fluctuation of the system in the first insolation annual cycle could also be deduced.

5 Project feasibility

Past publications have many considered parameters. Hence completing the project within time limit is considered positive.

Key:

section	target	action
1 = abstract	m = model	s = scripting
2 = introduction	a = analysis	d = debug
3 = methodology	p = parameters	v = validation
4 = results		work
5 = discussion		buffer / if any

Gantt chart:

Month	write	design	script	MSc lecture	model run
Dec		map	ms		
Jan	3	m	mdv		
Feb	2	a			
Mar	3		as		
Apr	45				
May					
Jun					
Jul	1				
Aug					

6 Budget

This project is free

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References

Baqué, Mickael et al. (2013). “The BOSS and BIOMEX space experiments on the EXPOSE-R2 mission: Endurance of the desert cyanobacterium Chroococcidiopsis under simulated space vacuum, Martian atmosphere, UVC radiation and temperature extremes.” In: *Acta Astronautica* 91, pp. 180–186.

Giraldo, Juan Pablo et al. (2014). “Plant nanobionics approach to augment photosynthesis and biochemical sensing”. In: *Nature materials* 13.4, p. 400.

Joshi, Sudeep, Ellexis Cook, and Manu S Mannoor (2018). “Bacterial Nanobionics via 3D printing”. In: *Nano letters* 18.12, pp. 7448–7456.

Markou, Giorgos, Dries Vandamme, and Koenraad Muylaert (2014). “Microalgal and cyanobacterial cultivation: the supply of nutrients”. In: *Water research* 65, pp. 186–202.

Nürnberg, Dennis J et al. (2018). “Photochemistry beyond the red limit in chlorophyll f–containing photosystems”. In: *Science* 360.6394, pp. 1210–1213.

Sawa, Marin et al. (2017). “Electricity generation from digitally printed cyanobacteria”. In: *Nature communications* 8.1, p. 1327.

Schuur, Edward AG et al. (2015). “Climate change and the permafrost carbon feedback”. In: *Nature* 520.7546, pp. 171–179.